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Standardizing Boom Test Procedures

Mason and Hanger-Silas Mason Co., Inc.
Leonardo, NJ

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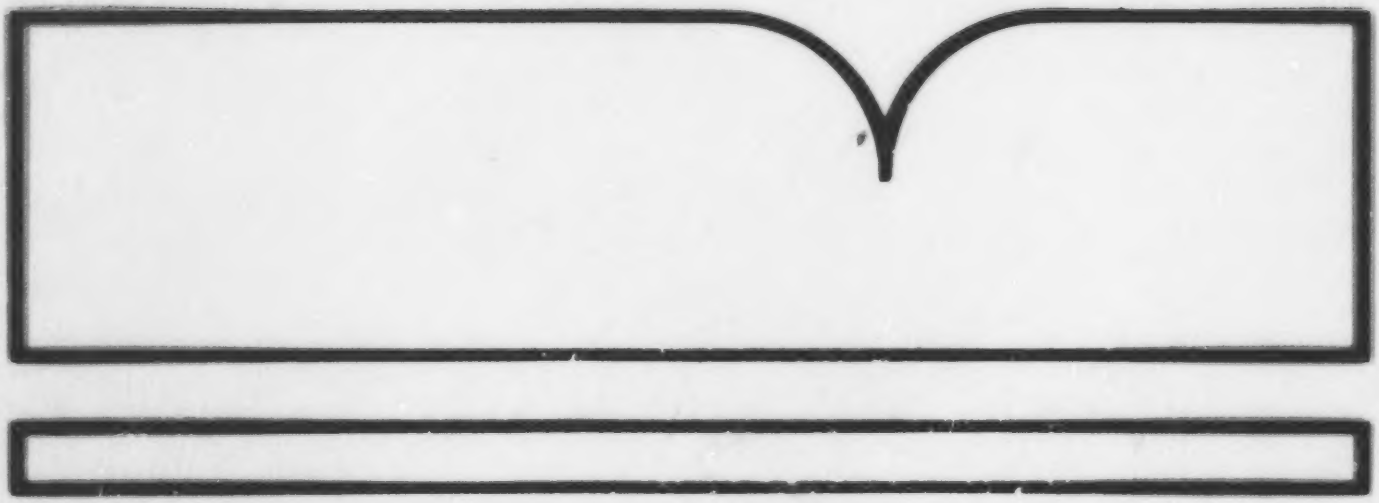

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STANDARDIZING BOOM TEST PROCEDURES

by

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Leonardo, New Jersey 07737

EPA Contract 68-03-3203

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16. ABSTRACT

The OHMSETT Interagency Technical Committee (OTIC) sponsored a combined series of in-tank and open-water tests of five booms that cover a wide range of sizes and design parameters. The tests were conducted at the United States Environmental Protection Agency's OHMSETT facility and in Sandy Hook Bay between November 1983 and May 1984. The in-tank tests measured the oil-holding performance of the boom; the open-water tests demonstrated the wave conformance and survivability. The objective was a correlation between the two sets of data.

There were five in-tank tests for each boom using a standardized test matrix for oil-holding ability. Wave conformance and endurance were observed under controlled conditions. The results of this testing compared favorably with past tests performed in the tank.

The five booms were deployed in the bay from 14 to 27 days, depending on the weather, and were videotaped to document their approximate sea-state limits. The wave conformance of the 500-ft booms deployed in the bay was similar to the conformance of the 100-ft lengths used in the tank, but lack of conformance was more obvious in the bay tests. The in-tank endurance tests did not correlate as well as expected with the open-water testing.

Additional testing to obtain both waveform and boom motion data is scheduled for the fall of 1984. These tests are designed to determine the minimum instrumentation and analysis needed to obtain acceptable measurements of boom response in irregular seas.

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Paper EPD 010, 1985 Oil Spill Conference

ABSTRACT

STANDARDIZING BOOM TEST PROCEDURES[1]

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ABSTRACT

The OHMSETT Interagency Technical Committee (OITC) sponsored a combined series of in-tank and open-water tests on five booms. The booms selected cover the wide range of sizes and design parameters often considered appropriate for spill control. The tests were conducted at the United States Environmental Protection (EPA) Agency's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) facility and in nearby Sandy Hook Bay between November 1983 and May 1984. The in-tank tests measured the oil-holding performance of the boom; the open-water tests demonstrated the wave conformance and survivability. The objective was a correlation between the two sets of data.

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The five in-tank tests for each boom used a standardized test matrix for oil-holding ability. Wave conformance and endurance were observed under controlled conditions. The results of this testing compared favorably with historical tests performed in the test task.

The five booms were deployed in the bay over an extended period. The length of deployment varied from 14 to 27 days depending on the local weather conditions. The booms were observed and videotaped to document approximate sea-state limits of the booms. The booms deployed in the bay were approximately 500 ft long. The tank tests used 100 ft lengths. The wave conformance in the two testings was similar. The five-fold increase in boom length made any lack of conformance more obvious, however. The data derived from the open-water testing were based primarily on visual observations and sea-state estimates. The in-tank endurance tests did not correlate as well as expected with the open-water testing. Determining the deterioration of a boom during long term deployment by in-tank testing was discounted by this program.

Additional testing to obtain hard data is scheduled for the fall of 1984. Both waveform and boom motion data will be collected to determine the limitations of the booms tested. These tests are modeled after work done in testing ships. These tests are designed to determine acceptable methods of measuring boom response to irregular seas and determine the minimum amount of instrumentation and analysis necessary to obtain the data.

These open-water tests will be executed in an area that is not fetch-limited as was the case in the Sandy Hook testing. Hopefully, a determination can then be made whether the more expensive open-ocean testing must be conducted to measure limitations in wave conformance and endurance or if this can be measured with in-tank testing.

This paper documents the results of the initial in-tank and open-water tests emphasizing techniques of testing and outlines plans for the future tests.

INTRODUCTION

Oil spill control booms are floating barriers designed for one of two functions: to contain or to divert oil. A significant amount of research and testing has been undertaken on booms. Because of this research, the state of the art has advanced considerably from the log barriers first used. The state of the art for boom testing has not kept pace with the booms themselves. Generally, boom testing has been aimed at answering specific questions about specific booms or boom components. The testing has not been generalized to give a uniform test method to evaluate general boom performance and provide a means of giving the overall picture of performance.

The OHMSETT Interagency Technical Committee (OITC) has undertaken to establish the needed test protocol. The procedure was to be developed at the United States Environmental Protection Agency's (EPA) Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) in Leonardo, New Jersey. The first step was to review the 10-year history of boom testing at the facility, the methods employed during these tests, and the outcome and to form a general opinion on the quality of the data and usefulness of the data for booms in general. This information was combined with the sketchy data available from boom tests in open water in order to establish a cost effective test method.

Boom tests in tank testing have had specific goals, generalized goals, and sometimes both. For example, tests of the Zooom Boom (Borst, 1981) attempted to determine the optimum tension member length for the specific boom and a generalized measure of boom loss rates. Boom loss rates were measured under similar conditions for two other booms (Borst, 1982; Borst, 1983) but the conditions were not identical. The lack of uniformity in this area was found throughout the history of tank testing even when the same type test was conducted. Principal differences in boom tests were found in oil distribution methods, volume and type of oil used, boom lengths and rigging.

Very little oil spill testing has been conducted outside of test tanks. Tests with mechanical equipment have been very limited in comparison with tests of chemical methods. Such tests have almost solely been conducted at spills of opportunity which make control of variables impossible. There have been a few notable exceptions, however, when systematic offshore tests have been conducted both with and without oil (Lichte, et al., 1982; Allen 1983; Corpuz and Griffiths, 1978; Abrams and Miller, 1973; Miller, et al., 1973).

Each test location has obvious shortcomings. Most notably, tank tests are limited by the tank capabilities, and the open-water tests are limited by either a lack of control, costs of execution, or both.

The OITC planned a two-step test procedure to develop a self sufficient protocol for uniform boom testing. The protocol must limit the shortcomings of each test location, maximize the relative benefits of each, be readily executable, and as cost effective as possible.

Development

Test plans were developed to conduct a two-stage evaluation of several booms. The first step was to determine the oil holding ability of the boom in question. Each boom was rigged in the test tank in a uniform manner, tested with the same quantity and type of oil, and subjected to the same test conditions. A set of five tests was selected. The booms were tested for first-loss and first-gross-loss[1] tow speeds in calm water, a 0.45-m harbor chop and a short period regular wave. The critical tow speed was determined, and a survivability test was run. The booms were then moored in nearby Sandy Hook Bay to document the wave conformance and determine how well the booms survived the exposure to the naturally occurring conditions in the harbor.

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1 Much of the jargon within this industry does not have specific definitions. The meanings as used within this paper are specified at the end of the References.

Five booms were selected to cover a range of boom sizes and designs that were considered appropriate for use in the open-water test site. The sponsoring agencies reviewed the booms selected and concurred. The manufacturer of each model selected was contacted and invited to participate in the program. The manufacturers that agreed to participate were required to provide 500 ft of the specific boom and pay all associated costs (shipping and onsite technical representatives, if desired). The booms selected were The American Marine Optimax, The Expandi Boom (4300), The Kepner Sea Curtain, The Crowley Marine 36-inch Permanent Boom, and the Goodyear 12-24 Sea Sentry. All manufacturers except Goodyear agreed to participate. The Goodyear boom could not be manufactured in the short time available, but the U.S. Navy supplied 500 ft from its Cheatham Annex stockpile.

SUMMARY OF PROCEDURE

The in-tank tests were intentionally designed to obtain primarily oil loss information using an abbreviated test matrix. Each boom was first towed to determine the calm-water first-loss tow speed—the speed at which the first evidence of entrainment could be observed. This was followed by a test to determine the calm water first-gross-loss tow speed, which was the tow speed at which drainage or other massive oil loss occurred. These tests were run in calm water; a 0.2-m high, 2.8-m long regular wave; and a 0.45-m harbor chop. In the fourth test, the booms were then towed at speeds expected to be outside their operational range. This test would give the maximum tow speed at which the boom could be towed without submarining, planing, or mechanical failure. This tow speed was named the critical tow speed. The final test was an endurance test. Each boom was exposed to a 0.5-m harbor chop for 45 minutes to obtain an accelerated cyclic stressing of the boom, recognizing that other aging parameters did not accelerate. This was considered to be a valid test based on previous work (Borst, 1983; Meikle, 1982).

TEST PROCEDURES

Instrumentation/set-up

Two tow points were constructed and mounted on the main bridge with an 11 m separation to attach the 30 m of boom to the OHMSETT main bridge. During the initial calm-water test on each boom, the tow force at known incremental tow speeds was recorded. These data were used to extrapolate the maximum allowable tow speed in calm water corresponding to the design strength of the tow point, with a safety factor. A load bolt was used in the western tow point connection during the first of the five tests on each boom.

The first test began at 0.5 kt and increased by 0.1-kt increments until loss occurred by entrainment of oil. This test determined first-loss tow speed in calm water and the tow force for the various tow speeds was recorded during this test. A pre-load of 0.38 m^3 (100 gal) of Circo-X Heavy oil (see Table 1) was distributed ahead of the boom catenary prior to each oil loss test.

After reaching the first-loss tow speed, the tow speed was increased by 0.1-kt increments with pauses at each step to observe and record data until first-gross-loss tow speed was noted. The tow force at each tow speed was recorded. After this test, the boom was disconnected from the strain gauge and connected directly to the tow point because the tow forces at the higher tow speeds were anticipated to be above the recommended range of the strain gauge.

In the second test, a 0.19-m-high, 2.77-m-long breaking wave was created. Starting at 0.25 kt, the tow speed was increased by 0.1 kt until first-loss tow speed was reached. The first-loss tow speed and mode of loss were recorded for each boom.

The third test determined first-loss tow speed in a 0.45-m- high harbor chop. Starting at 0.25 kt, tow speed was increased by 0.1-kt increments. Mode of loss, under-boom or over-boom, and the first-loss tow speed were recorded.

In the calm-water critical tow speed tests, each boom was towed at 0.5 kt, and the tow speed was increased by 0.5-kt increments to 2.0 kt. Then the speed was increased by 0.25-kt increments until the boom failed to float properly by either planing or submarining. In the durability test, each boom was towed intermittently at 0.5 kt in a 0.45-m high harbor chop. At other times the towing bridge was stationary. A tow-back rope connected from the apex of the boom to the auxiliary bridge facilitated towing North. The 45-minute test did not include the wave build-up and die-down periods.

SUMMARY OF OPEN-WATER TEST PROCEDURE

Site selection

The site selected for the deployment was 350 m northwest of the pier at the U.S. Naval Weapons Station-Earle (see Figure 1). This area was chosen because of the ease of access from the OHMSETT test facility, which is located on the shore at the pier and served as the base of operations. The pier served as a stable observation platform and deployment point. The USCG Station Sandy Hook provided vessels capable of towing the 152-m boom sections. A 488-m-long, 244-m-wide area in the bay was chosen. The mean-low-water depth, was from 5 to 7 m. The predominant winds were expected to be from the north-northwest (see Lett, 1976 and NOAA, 1977). It was recognized from the start of planning that the pier would block waves from the east. This was of no particular concern as the eastward fetch was severely limited and no waves of significance were expected with easterly winds. The waves were measured using a wave-rider buoy. A description of the NUSC wave rider buoy can be found in several sources (Lichte, et al., 1983; Shonting & Gordon, 1984; Shonting and Robertson, 1980).

Mooring

Four concrete sinkers were positioned by the USCGC SORRELL on 23 March 1983 near 40° 27'N74° 3'W using three geodetically fixed targets on the nearby shore. The sinkers were positioned in two pairs. The sinkers in each pair were separated by 61 m. Each pair was positioned so that sinkers ran on an east-west line. The separation between the pairs was 230 m.

The sinkers were trapezoidal concrete blocks weighing approximately 2300 kg each. A large steel chain link was half imbedded in the concrete to provide an attachment point. A 6-m length of 3/4-inch diameter chain was shackled to the large link. The chain was shackled to a 26-m length of 1 1/8-inch nylon rope, which was shackled to the mooring buoy. A line rising to the crown buoy was attached to the 3/4-inch chain four links from the main attachment on the sinker. Nylon rope was also used for this attachment. A Notice to Mariners was posted through the Third Coast Guard District after the moorings were put in position.

Initially, the booms were connected to the mooring buoy with nylon rope. The nylon wore through on several of the segments during the second week and was replaced with 3/8-inch diameter wire rope (7 x 16 IWRC). The wire rope was used as a replacement for nylon throughout the mooring systems. Divers replaced the line from the mooring buoy to the sinkers. The surface lines from the mooring buoy to the booms were replaced by men in Zodiac boats. In each replacement, the wire rope installed was roughly 1 m longer than the nylon it replaced.

Lighting

Five pendulous light floats were attached to each boom to mark its location and avoid creating a hazard to navigation. The lighted floats were attached to the boom at the tension member on the four booms with an exposed tension member. They were attached to the Crowley Petro-Barrier at the anchor points designated on the boom,

because this boom was self tensioning. Each boom had three light floats with lantern lamps 1-m above the water surface. The lens on these lights were painted yellow. The cables from the boom to the mooring buoys were also marked using floats with a set of double lamps with red lenses. The lower light was 1-m above the surface, and the upper light was 1-m above the lower.

These lights with pendulous counterweights worked well. However, in higher seas the upright members broke. This was particularly the case with the double sets.

Documentation

From the time of the first boom deployment until the final boom retrieval, the booms were observed for 15 hours per day (two 8-hour shifts). This provided more than dawn-to-dusk coverage. When there was sufficient light each boom was videotaped for 10 minutes on-the-hour using a black-and-white IVC 40M video camera with a TV16 25 to 100 mm lens and an 2X extender. The recorder used was a Panasonic NV 8400 ½-inch recorder. The video coverage concentrated on the apex of the catenary. The taping was done from the second floor of the Port Services Office on Pier 3 (see Figure 2). This gave the required elevation and a stable, sheltered vantage point. The boom watcher kept logs of the boom orientation, wind speed and direction, and counter indications on the video deck. The National Weather Service continuously-broadcast weather report from New York City (162.55 MHz) was recorded on the audio track of the tape during each recording. The booms were photographed with 16-mm movie cameras and 35-mm cameras from the boats and from Pier 3. The deployment and retrieval of each boom was also taped. In higher waves, the 35-mm cameras were abandoned for pocket cameras which were easier to operate in the small rolling boats and less expensive in case of loss.

Results

The particular results and observations of individual boom performance are not directly applicable to this paper on procedures. Each boom tested demonstrated a clear-cut performance shortcoming, and most were exposed to sea conditions in excess of those in which the boom could be expected to effectively contain an oil slick. Although the methods employed in the procedure were not considered to be sufficient for the development of a protocol, the following is needed.

CONCLUSIONS

- The test area was fetch limited and did not produce the sea conditions desired.
- The boom mooring configuration with boom gap equal to 50% of the boom length was marginally too small. A 67% gap would have been better, however any gap from 50% to 75% the boom length would probably have worked.
- The in-tank wave conformance paralleled the open-water wave conformance. Any open-water lack of conformance was more obvious than the in-tank lack of conformance. This was probably due to the five-fold length increase.
- The oil-holding abilities of the booms were within the traditional norms of previous tests (McCracken, 1977; McCracken and Schwartz, 1977).
- The in-tank endurance test did not give an accelerated aging of these booms.
- Test results were too subjective. Quantified test results are needed to establish a protocol. Hard data are needed for the tests.
- A standard method of lighting booms must be specified. The method used was not acceptable primarily because the counter weights tangled in the mooring line and the upright members broke.

RECOMMENDATIONS

- Additional background testing must be conducted prior to establishing a standard test protocol.

- New test areas should be more open to obtain the sea conditions required for the tests. The future tests must be conducted in seas through at least 2.5-m high.
- A theory of measuring boom conformance must be developed.
- A method of conformance measurement must be specified.
- The theory and method must be proven.
- The protocol should be designed to specify the minimum amount of data acquisition needed to document the boom performance.

FOLLOW-UP TESTS

It is felt that the incidence of splashover or skirt exposure is a direct indication of the boom's conformance. Ship designers are interested in a similar phenomenon; the frequency of bow submergence or bow slamming. They have developed a theoretical means of measuring and predicting these occurrences (Comstock, 1967). It appears to be appropriate to borrow the ship designers' research and hypothesize that the response of a boom to random waves can be expressed as the boom's response to component waves.

This relies heavily on the oceanographer's theory of superimposition, that is, that a random sea is simply the sum of component sinusoidal (regular) waves. The borrowed hypothesis must be expanded to include the measurement of the boom response and determination of the boom effectiveness. The definition of response then implies that the measure of the response of a boom to any wave or wave component can be expressed as the ratio of the boom movement at the wave frequency to the movement of the water surface at the same frequency. It should be noted that the concept of response is associated with other industries in addition to ship design. Perhaps a more comfortable analogous test procedure is that this method is very similar to the one that Consumers' Union uses to test stereo loud speakers. They publish a speaker frequency response curve for their tests (Consumer Reports, 1984).

The principal tool needed to test the hypothesis is a means to measure the changes in water surface elevation and the boom position concurrently over a prolonged period. These measurements must then be changed to the frequency domain components so that the two measurements can be compared at each frequency to determine the response of the boom at each frequency within the spectrum. The method then uses proven statistical methods to describe the boom response to the sea conditions.

MEASUREMENT TECHNIQUES

The boom motion will be measured with both pressure transmitters and coupled accelerometers. The accelerometers will be mounted in pairs on the boom as close to the estimated center of rotation as possible. This will be done to minimize the magnitude of the measured angular accelerations without affecting measurement of translational acceleration. The translational accelerations can then be double-integrated to obtain boom motion. Pressure transmitters will be attached to the bottom of the boom skirt. This pressure measurement will then be changed to a depth measurement, knowing the specific gravity of the surrounding water. It will be important to ensure watertight integrity of the system's instrumentation and cabling as well as minimizing the weight and size of the components.

Data will be recorded in high-density digital format using a watertight data logger. It is anticipated that, for much of the time, it will not be of interest to log the sensor measurements and that, since there is considerable risk associated with data tape changing, data will need to be logged on the command of an on-scene observer. The decision to record the information will be made based on sea-spectra and boom orientation. It is hoped that either the accelerometer or pressure sensor data will be redundant so that the associated instrumentation for one of the measurements can be eliminated. The boom tension and orientation will need to be measured in addition to environmental parameters to complete the final computation.

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EXACT DEFINITION OF TERMS AS USED IN PAPER

Boom height: distance from top to bottom of boom

Boom draft: distance from normal calm-water line to the bottom of the skirt

Boom skirt: that portion of the boom from the lowest point to the bottom of the flotation

First-loss tow speed: tow speed at which the contained oil is first shed from the boom by entrainment

First-gross-loss tow speed: tow speed at which the oil preload is first lost from the boom by drainage

Tow speed: relative boom-water speed difference

Critical tow speed: speed at which a boom fails to maintain a mechanical barrier on the water surface by planing, submarining, or mechanical failure

Submarining: complete submergence of the boom due to excessive tow speed

Planing: exposure of the bottom of the boom skirt due to excessive tow speed

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Messrs. Ajit Shah of Ajit Shah, Inc., Frank Meyers of Kepner Plastic, Trygve Enger of Crowley Environmental and James Pierce of American Marine provided the boom sections for the extended period necessary for the testing and each gave on-going advice on the technical aspects of their respective products.

The OHMSETT Interagency Technical Committee provided the funding for the program. This consortium is composed of the U.S. Minerals Management Service, U.S. Coast Guard, U.S. Environmental Protection Agency, Canadian Environmental Protection Service and the U.S. Navy. The current Chairman of the OITC is Mr. Edward Tennyson of the Minerals Management Service.

Several units of the U.S. Coast Guard provided additional assistance. The Captain and crew of USCGC SORRELL from the Third District Aides to Navigation positioned the sinkers. The USCG Station Sandy Hook provided the tow vessels on each occasion required to tow booms between the launch point and the test area, and tenders for the diving exercises. Each vessel arrived with a helpful, well-trained crew. The experience of these various crews greatly expedited deployment and retrieval operations. The USCG Atlantic Strike Team provided Zodiac boats for the duration of the testing. The U.S. Naval Weapons Station-Earle, commanded by Captain R. Turner, provided on-going support. In particular, BMCM Colvin, the Port Services officer, and his staff provided crucial support and services during the month-long tests. Master Chief Colvin provided routine access to the pier and the restricted waters around the pier, a station within his office space for observation of the booms, and instrumentation for local weather conditions. He supported this program while continuing normal pier operations and an extensive refurbishment effort to the pier. The Naval Underwater Sea Systems Command (NUSC) provided wave measurement equipment and oceanographers. The U.S. Navy also provided the Goodyear Boom for testing and the mooring systems.

TABLE 1. CIRCO X HEAVY OIL PROPERTIES

Sample Number	Interfacial Tension (dynes/cm)	Specific Gravity	Viscosity (cSt)	Surface Tension (dynes/cm)
1	12.8	0.930	880	34.9
2	12.2	0.930	930	34.8

NOTE: The test oil was sampled with each fill of the oil distribution tanks. Surface tension and interfacial tension with tank water were measured at room temperature (22.5°C) using a Fisher Scientific Model 21 Surface Tensiomat. The viscosity was measured using a Brookfield Model LVT viscometer at room temperature and at an elevated temperature. Viscometer results were converted to centistokes using the relationship expressed in ASTM D-2161-74, Section 6, and plotted on ASTM D341 viscosity temperature charts for interpolation at ambient conditions. The specific gravity was determined with hydrometers as specified by ASTM D-1298-67.

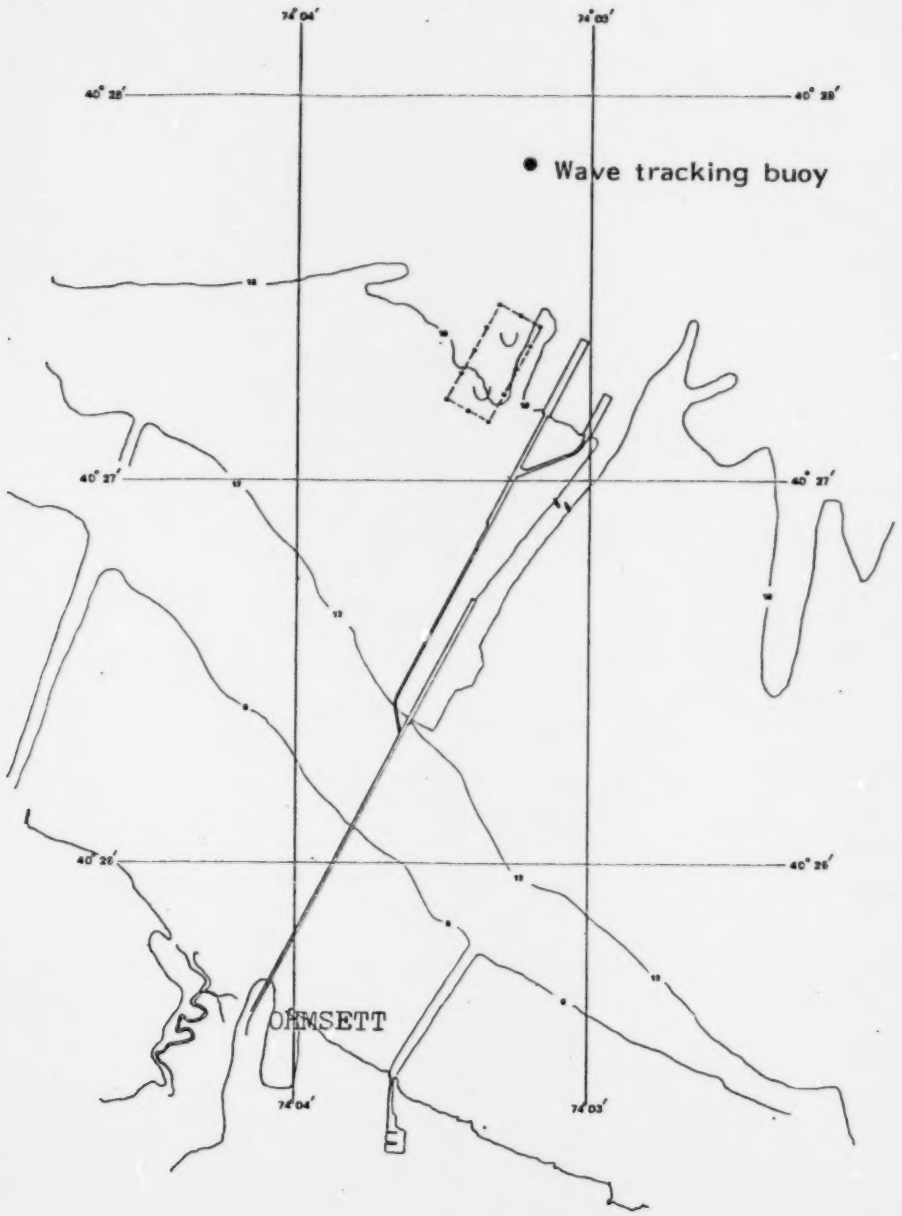

Figure 1. The area selected for the boom deployment was 350 m northwest of the USN pier on the Weapons Station-Earle. The test area is marked with the dotted lines. The figures is taken from NOAA nautical chart 12330. The bottom contour lines shown are soundings in feet.

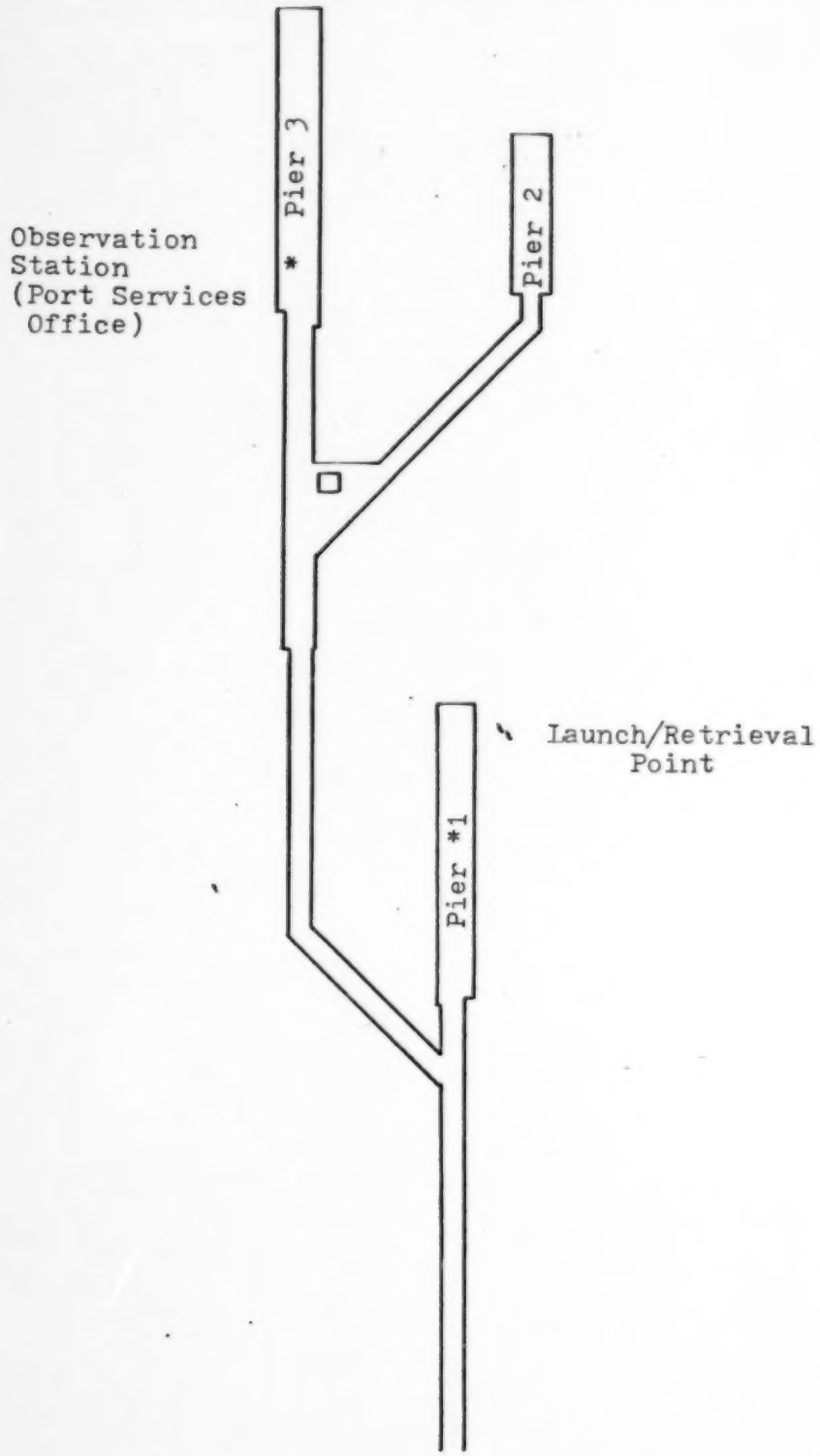

Figure 2. The pier at U.S. Navy Weapons Station-Earle served as the observation platform and launch/retrieval point for the open-water tests.